

Forecasting the Unpredictable

Application of Quantitative Risk Analysis (QRA) to Risk Management
in the International Space Station (ISS) Program

Project Management Challenge 2009

February 24-25

Daytona Beach, FL

Impetus

- *Late '90s found ISS Program realizing a series of budget 'underruns' due largely to work slippage tied to the delay in launch of the principal Russian element*
- *A stretching schedule meant a rise in cost risk level, heightening uncertainty regarding rate at which risks might impact budget reserves*
- *Faced with the most technically challenging portion of assembly to-date, the ISS management team added many high-valuation risks to threats list*
- *Seeming underruns suddenly turned into high-profile projections of overruns!*

Situation

- *Simple 2-tier risk classification system in place – 'liens' & 'threats'*
- *Formation of ISS Assessments Office (since grown to Assessments, Cost Estimates & Schedules – ACES)*

Challenge

- *Devise means of objectively assessing likely threats impact to reserves*

Background

Initial approach

- *2-tiered risk classification system replaced with 3-tiered threat levels*
 - *Level 1 – greater than 50% likelihood of occurrence with impact to reserves*
 - *Level 2 – approximately even chance of occurrence*
 - *Level 3 – less than 50% likelihood of impact to reserves*
- *Potential threat valuation, cost phasing estimated by submitting organization*
- *Still lacked objective means of assessing potential impacts to reserves – how much of a several-\$100M list of threats would materialize?*
 - *Subjective consensus was that threats were inflated & front-loaded*
 - *Experience was that relatively smaller subset of listed threats resulted in cost impacts*

Refined approach

- *Develop QRA-based threat realization projection process*
 - *Monte Carlo based analysis*
 - *@Risk™ platform*
- *Contracted Futron® to develop QRA capability*
 - *Toolset*
 - *Models*
 - *Process*

Background

The cost & realization likelihood dimensions

- *K-factors – normalized cost triangular distributions – were developed by Futron, based on data from 347 completed NASA projects/programs*

- *Management* *0.80 / 1.04 / 1.27*
- *Process* *0.83 / 1.07 / 1.32*
- *Design / dev.* *1.02 / 1.26 / 2.00*

Order of
Increasing
Cost Risk

- *Probabilistic factors tied to threat level were also implemented by Futron, based on the concept of dividing the probability spectrum into thirds*

- *Level 3 threat* *0.00 / 0.17 / 0.33*
- *Level 2 threat* *0.33 / 0.50 / 0.67*
- *Level 1 threat* *0.67 / 0.83 / 1.00*

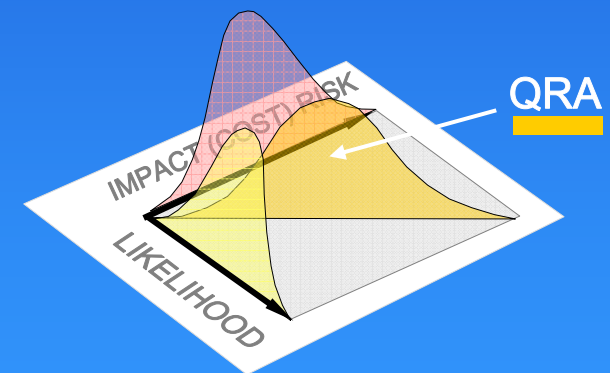
Order of
Increasing
Occurrence Risk

The combined process

- *QRA tool, built around @Risk™, was designed to perform a Monte Carlo assessment based on listed \$ value x K-factor distribution x level distribution*
or:

estimated mitigation cost x likely cost performance x likelihood of occurrence

- *Correlates with standard impact v. likelihood risk matrix*
- *Monte Carlo output is S-curve; 80th %ile value is used*

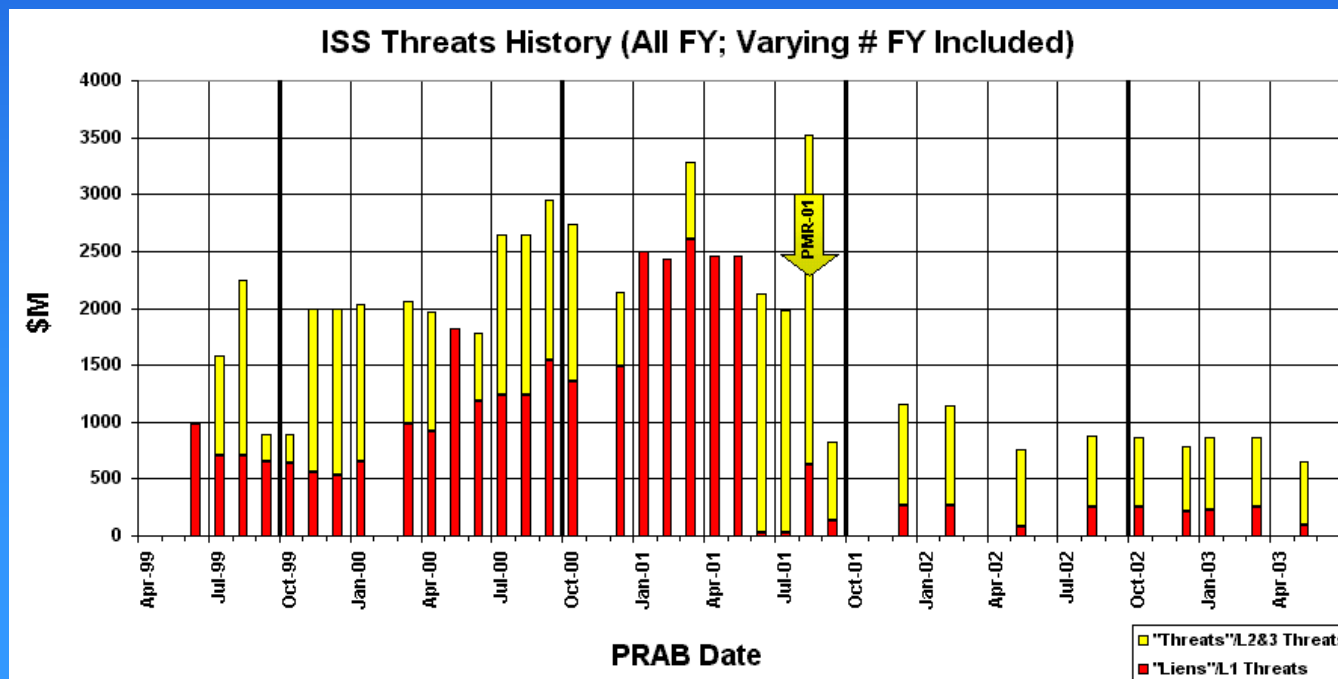


Original QRA

Initial results

- *Current-year projection of threat realization / impact to reserves improved, but...*
 - *Out-year threat projections remained unrealistically high*
 - *Projections in all years exhibited unrealistically volatile behavior from control board to control board, as items were added / deleted, often for non-technical reasons*
- *Prompted idea of 'tuning' QRA realization probability distributions to reflect actual ISS Program history*

The search for a pattern

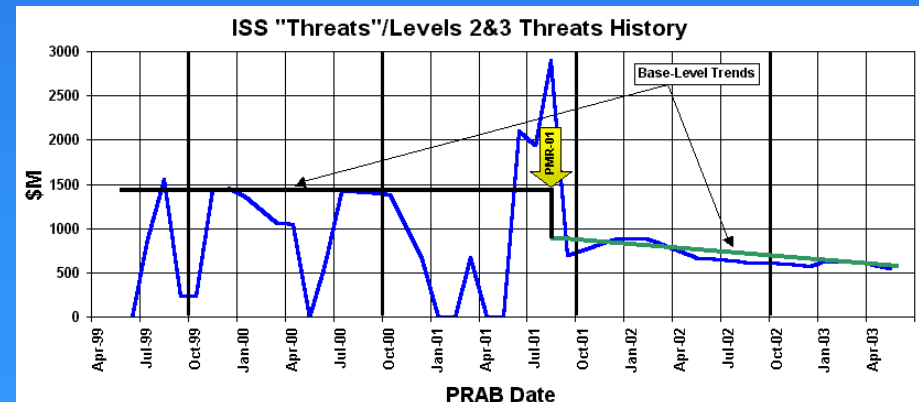
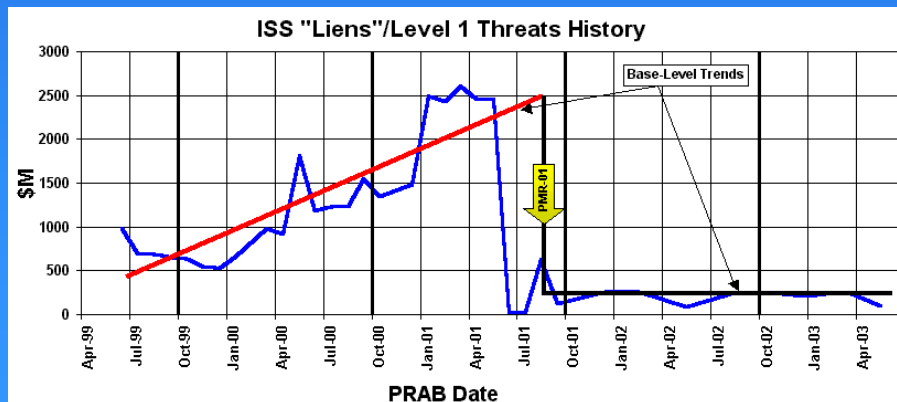
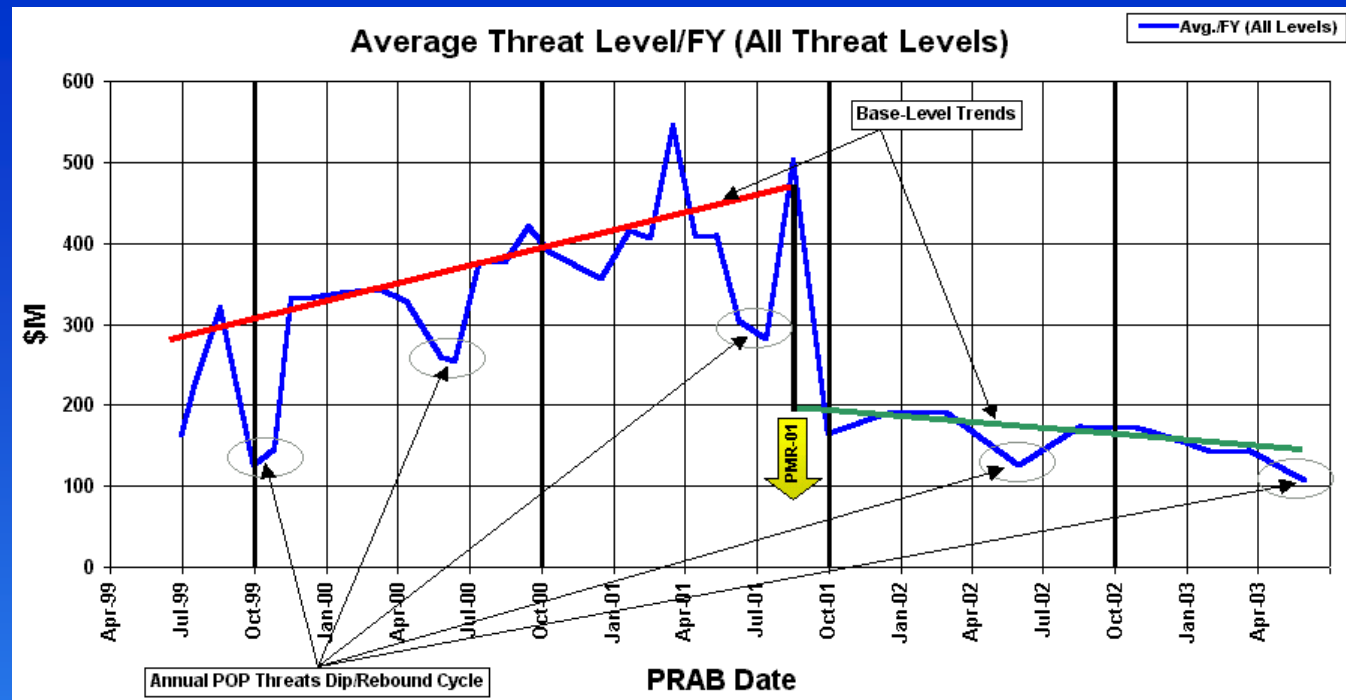


PRAB = Program
Risk
Advisory
Board

Original QRA

Trending threat list data...

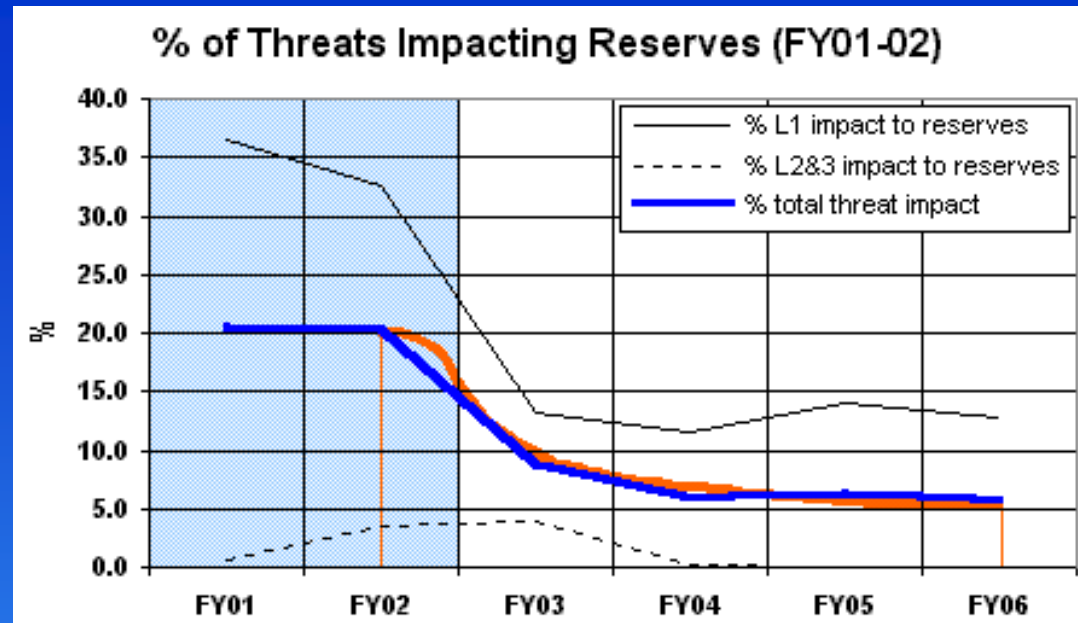
- 'Liens' &
Level 1s
v.
- 'Threats' &
Level 2s +
Level 3s



Tuning the QRA

Tracking threat realization...

- *'Known unknowns'*
- *Actual impacts to Program budget reserves only*
- *Historic data unavailable at the time to do same for 'unknown unknowns'*

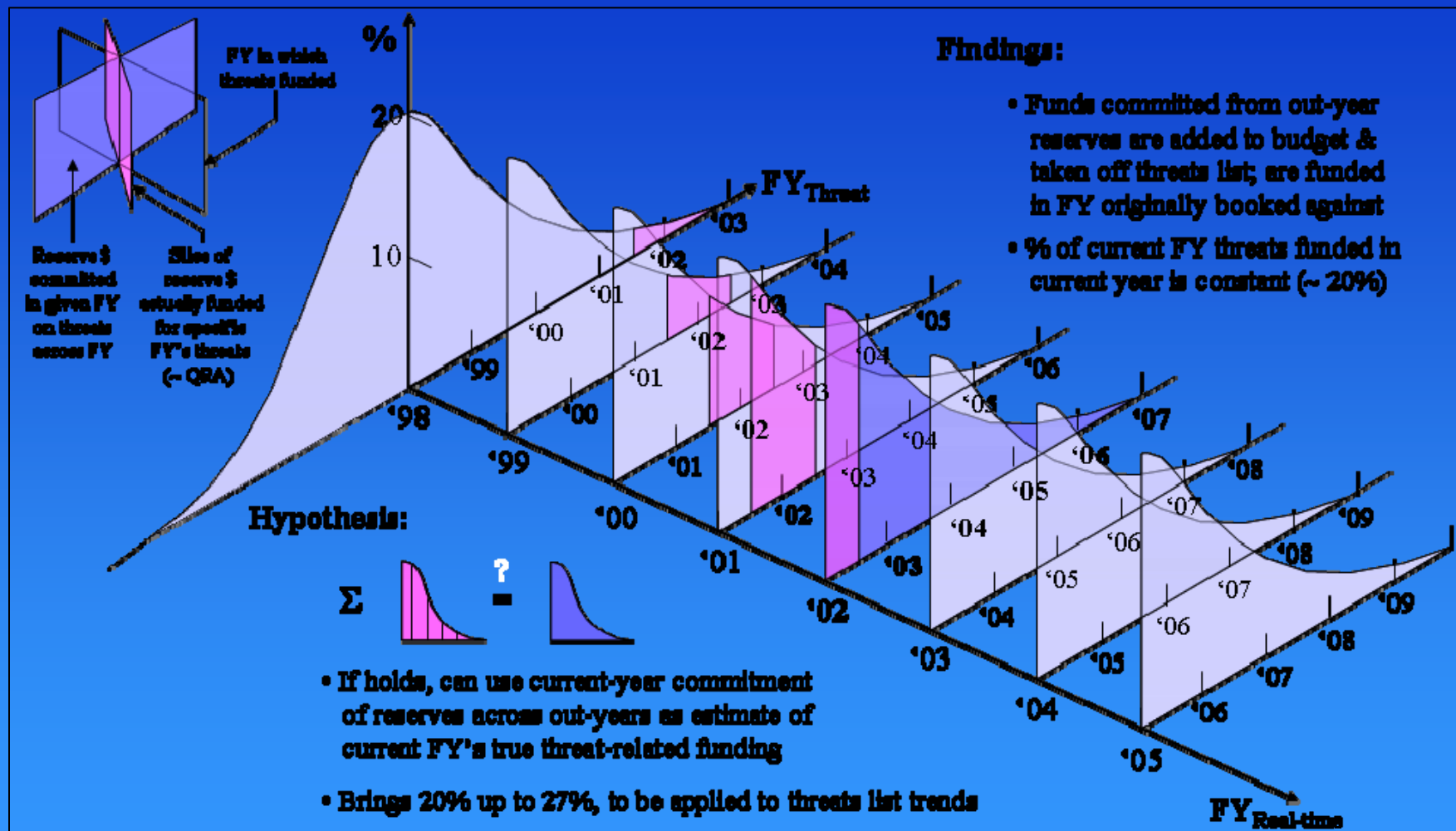


Observations

- *% of listed threat values (all levels) realized in the year of execution held steady at 20%, despite significant shift in risk management between FY01 & FY02*
- *Current-year commitment of out-year reserves for risk mitigation totaled 7%*
 - *Trailed off as the right half of a Gaussian distribution*
 - *When added to the 20% current-year impact to reserves totaled 27%, remarkably close to management team's anecdotal '30 cents on the dollar' rule of thumb for realized threat-related impacts to reserves*

Tuning the QRA

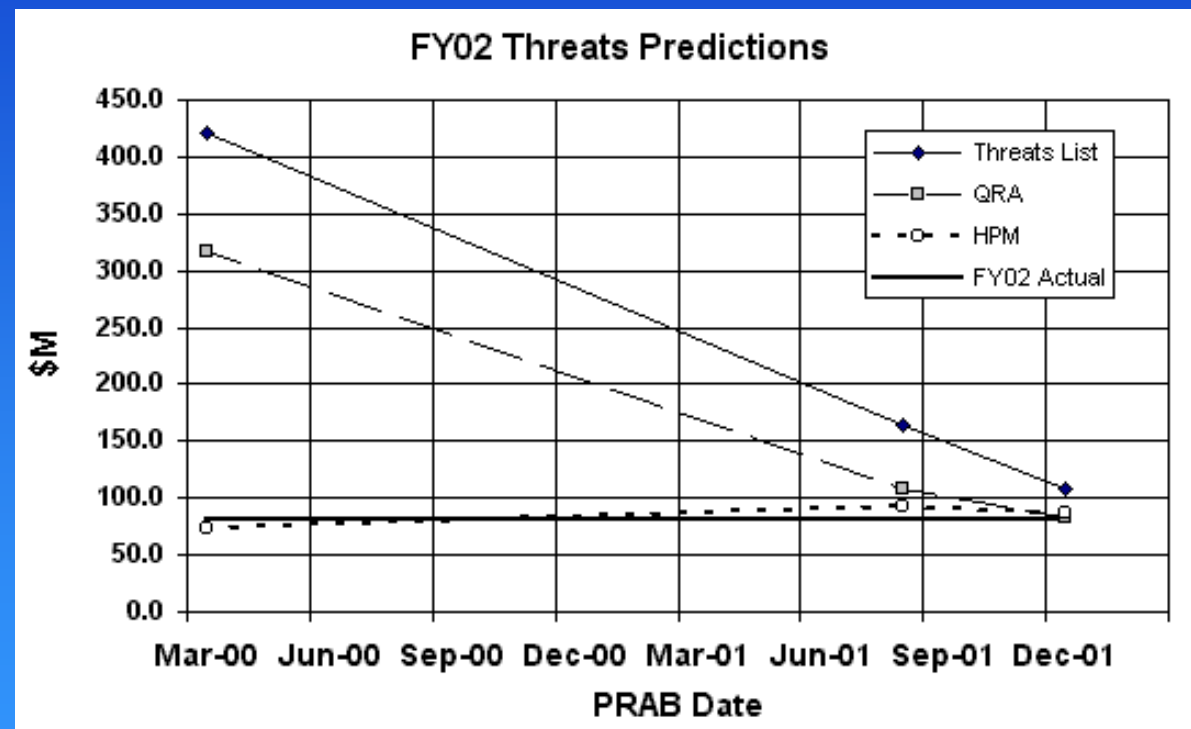
The hypothesis



Tuning the QRA

Testing the hypothesis

- *Based on the observed trends in threat realization, an empirical formulation was derived to transform raw threats list data into a projection of actual impacts to reserves – the Historic Projection Methodology (HPM)*
- *Applies 20% factor to mean of given year's history of threats list valuations for level 1 & levels 2, 3 (current year)*
- *27% factor applied to full threats list's mean value for out-year projection*
- *Test case (FY02) to within 8% of eventual actual data, two years in advance*



Tuning the QRA

Tuning the threat realization probability distributions

- Initial Futron distributions divided probability spectrum into thirds, one per level
- Data indicated preponderance of realized threats to be Level 1s
- Split Level 1 threats into current-year & out-year categories

- Built in a 20% margin of conservatism for current-year Level 1s

- Assumed symmetric distributions

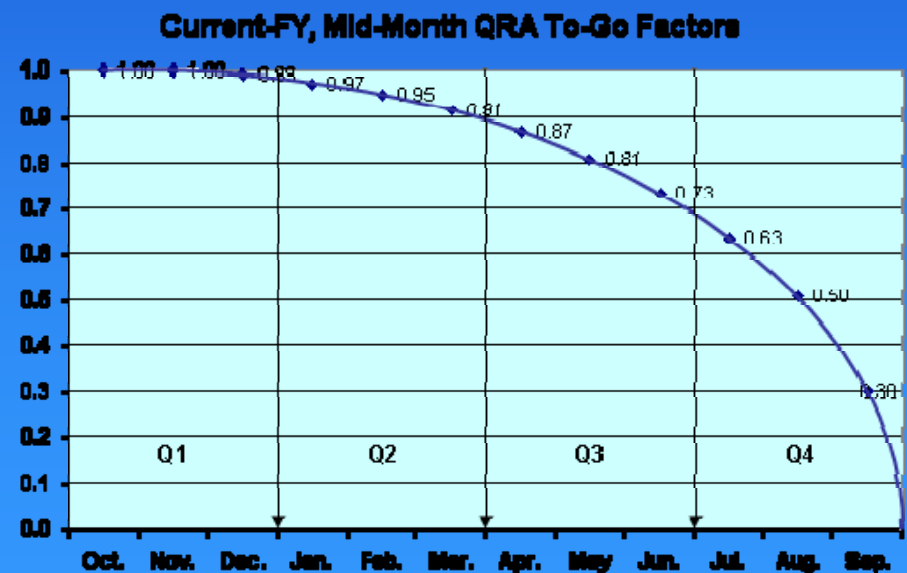
- In simplified case at right, tuned QRA projects \$8.7M current-year / \$6.5M out-year impact on \$30M/year threats, v. untuned \$15M/year

	Was (QRA)	Is (QRA-2)																																																																																																																																																
Probability	<ul style="list-style-type: none">• 0-100% probability spectrum evenly divided into thirds• L1: Expected value 84% (all FY)• L2: Expected value 50%• L3: Expected value 17%• Assumption in absence of data	<ul style="list-style-type: none">• L1/2/3 probability distributions centered per threats study• L1: Exp. value 79% (current FY) Exp. value 57% (out-years)• L2: Exp. value 6%• L3: Exp. value 2%																																																																																																																																																
Simplified Visual	<p>Probability Spectrum</p> <p>Will Happen Won't Happen</p> <p>100% 0%</p>	<p>Probability Spectrum</p> <p>Will Happen Won't Happen</p> <p>100% 0%</p>																																																																																																																																																
Simplified Example	<table><tr><th></th><th>(\$M)</th><th>FY</th><th>FY+1</th><th>FY+2</th><th>FY+3</th><th>FY+4</th><th>FY+5</th></tr><tr><td>Threats L1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>L1:</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td></tr><tr><td>L2:</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td></tr><tr><td>L3:</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td></tr><tr><td>QRA</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>L1:</td><td>8.4</td><td>8.4</td><td>8.4</td><td>8.4</td><td>8.4</td><td>8.4</td><td>8.4</td></tr><tr><td>L2:</td><td>6.0</td><td>6.0</td><td>6.0</td><td>6.0</td><td>6.0</td><td>6.0</td><td>6.0</td></tr><tr><td>L3:</td><td>1.7</td><td>1.7</td><td>1.7</td><td>1.7</td><td>1.7</td><td>1.7</td><td>1.7</td></tr></table>		(\$M)	FY	FY+1	FY+2	FY+3	FY+4	FY+5	Threats L1								L1:	10	10	10	10	10	10	10	L2:	10	10	10	10	10	10	10	L3:	10	10	10	10	10	10	10	QRA								L1:	8.4	8.4	8.4	8.4	8.4	8.4	8.4	L2:	6.0	6.0	6.0	6.0	6.0	6.0	6.0	L3:	1.7	1.7	1.7	1.7	1.7	1.7	1.7	<table><tr><th></th><th>(\$M)</th><th>FY</th><th>FY+1</th><th>FY+2</th><th>FY+3</th><th>FY+4</th><th>FY+5</th></tr><tr><td>Threats L1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>L1:</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td></tr><tr><td>L2:</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td></tr><tr><td>L3:</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td></tr><tr><td>QRA-2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>L1:</td><td>7.9</td><td>5.7</td><td>5.7</td><td>5.7</td><td>5.7</td><td>5.7</td><td>5.7</td></tr><tr><td>L2:</td><td>0.8</td><td>0.8</td><td>0.8</td><td>0.8</td><td>0.8</td><td>0.8</td><td>0.8</td></tr><tr><td>L3:</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td></tr></table>		(\$M)	FY	FY+1	FY+2	FY+3	FY+4	FY+5	Threats L1								L1:	10	10	10	10	10	10	10	L2:	10	10	10	10	10	10	10	L3:	10	10	10	10	10	10	10	QRA-2								L1:	7.9	5.7	5.7	5.7	5.7	5.7	5.7	L2:	0.8	0.8	0.8	0.8	0.8	0.8	0.8	L3:	0.2	0.2	0.2	0.2	0.2	0.2	0.2
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Tuning the QRA

Process modifications

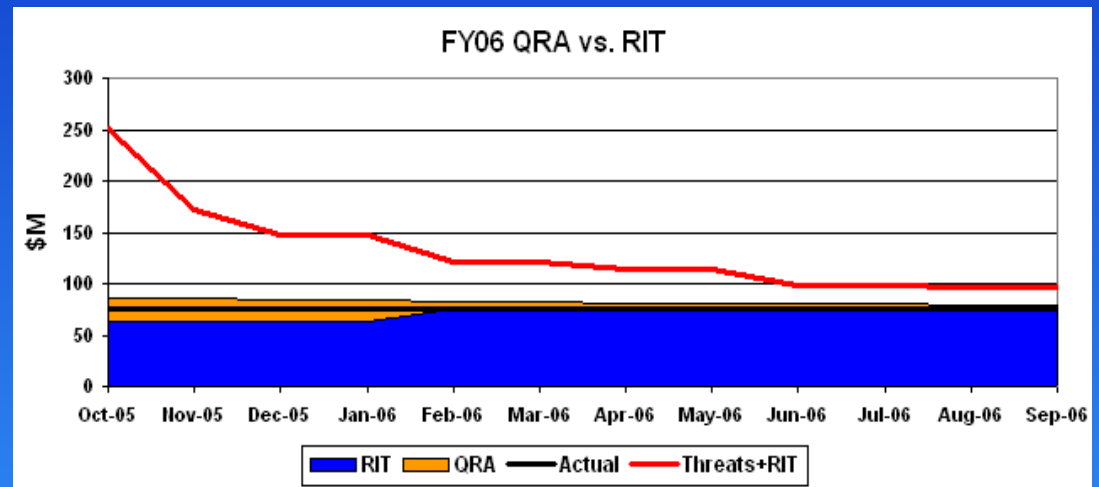
- *Creation of Level 0 category – pass-through threats*
 - *Certain to occur*
 - *Reasonably known cost impact*
 - *Inclusion in Monte Carlo analysis would render its results statistically invalid*
- *Maintenance & reporting of running average of QRA point estimates*
 - *In keeping with lessons-learned with HPM & study that preceded it*
 - *Smoothed out artificial volatility of threats list*
- *Provision for annual tuning of QRA*
- *Reporting of QRA as a to-go value by subtracting out reserve impacts due to threats (RITs)*
- *Incorporation of current-year elliptic tail-off (to-go) factor*
 - *Takes QRA prediction to zero at end of year of execution*
 - *Accounts for inability to cost funds to mitigate threats realized late in fiscal year*



Other Improvements

Usage & overall predictive accuracy

- *QRA projections are integral to several program control assessments, including fiscal year expenditure forecasts & cost containment analyses*
- *With annual tuning, QRA forecasts continue to be reasonably accurate*
- *In representative example given at the right, QRA prediction is modestly conservative at start of fiscal year (~30%), & converges smoothly to eventual actuals*



Summary

- *Tying estimates of cost impacts to identified threats & adding quantitative analysis to the risk assessment process have boosted forecasting accuracy*
- *As a result, QRA is now integral to successful program control in the ISS Program*

Results

Recent trends & developments

- *Last two fiscal years have shown steady shift in threat realization trends*
 - *Current-year impacts to reserves down; balanced by increased activity in prior years*
 - *New trends in keeping with Program's continued transition into operations phase*
- *Prompted new look at threats realization history*
 - *Several more years of actual impacts data*
 - *Looking to predict not only overall impact to reserves, but sources (i.e., level & type of threat) as well*
- *Product of ongoing assessment will not only address level-related tuning, but will for first time tune K-factors to ISS Program history*

The future...?

- *If a program's risk management system is designed from the outset to track the right data, an exciting possibility presents itself: predicting unknown unknowns*
 - *Total nondiscretionary reserve impacts – threat-related impacts = unk.-unk. impacts*
 - *Characterization of unk.-unk. impacts likely to take form of a Cost Est. Relationship*
- *If enough programs of similar class do this (e.g., large aerospace development), general CER(s) can be developed for use by new programs*

Epilogue